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NEW RESULTS IN INFLUENCING LIFT OF WINGS

by Albert Betz
as translated by Friedrich Wagner

Engineering Study No. 083

for the Office of Naval Research
Contract Nonr-201(01)

September 1952
University of Wichita
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A FEW YEARS AGO MR. BLUME ADVISED US TO TRY TO REPLACE THE USUAL MOVABLE RUDDER WITH SOME OTHER DEVICE, WHICH DID NOT CONTAIN SO MANY SENSITIVE PARTS. I HAVE FOLLOWED THIS SUGGESTION. RESEARCH ON THE SUBJECT HAS LED TO VERY SATISFACTORY SUCCESS. THERE WAS ANOTHER VERY SIGNIFICANT RESULT, SINCE DURING THE EXPERIMENTS THE LIFT COEFFICIENTS OF THE WINGS EXCEEDED THE USUALLY OBTAINED RESULTS. I WANT TO REPORT BRIEFLY ABOUT IT.

AT FIRST I PROPOSED A DEVICE, WHICH AFTER SOME PRELIMINARY TESTS WAS SHAPED ACCORDING TO FIGURE 1.

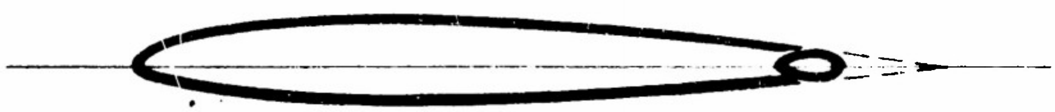

FIGURE 1.- WING WITH ROUNDED TRAILING EDGE AND BLOWING SLOTS.

THEREBY THE TRAILING EDGE IS NOT SHARP, AS USUAL, BUT BLUNTLY ROUNDED. FOR THE NORMAL PROFILE THE LIFT OF THE WING IS DETERMINED AT A GIVEN ANGLE OF ATTACK BY THE SMOOTH CONFLUENCE AT THE TRAILING EDGE. THE POSITION OF THIS STAGNATION POINT AT THE TRAILING EDGE IS DETERMINED BY THE SHIFTING OF BOUNDARY LAYERS ON THE SUCTION AND PRESSURE SIDES. IT MUST BE POSSIBLE TO CHANGE THE POSITION OF THIS STAGNATION POINT AND TO CHANGE WITH IT THE LIFT OF THE WINGS BY INFLUENCING THE BOUNDARY LAYER. FOR THIS REASON THERE ARE TWO SLOTS NEAR THE TRAILING EDGE, THROUGH WHICH THE AIR IS DISCHARGED THROUGH THE SLOT ON THE SUCTION SIDE. THE FRICTION LAYER ON THIS SIDE BECOMES RICHER

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IN ENERGY CAUSING LESS DIVERSION THAN ON THE PRESSURE SIDE SO THE POINT OF SEPARATION MOVES TOWARD THE PRESSURE SIDE. THAT MEANS AN INCREASE IN THE LIFT, EXACTLY LIKE A FLAP AT THE TRAILING EDGE IF THIS FLAP WAS DEFLECTED DOWNWARD. INVERSELY, THE DISCHARGE ON THE PRESSURE SIDE CAUSES A DECREASE IN LIFT. THE EXPERIMENTS DONE BY ONE OF MY ASSISTANTS, MR. SCHWIER, SUBSTANTIATED THIS CONSIDERATION. WITH PROPORTIONALLY SMALL DISCHARGE QUANTITIES, THE CHANGE IN THE LIFT COEFFICIENT C_A CAN EASILY REACH 0.5 WHICH IS COMPARABLE TO THE EFFECT OF A DEFLECTED AILERON. THE QUANTITY COEFFICIENT IS ABOUT .012, THAT MEANS, THE DISCHARGED QUANTITY EQUALS IN UNDISTURBED AIR FLOW A THICKNESS OF .012 OR 1.2% OF THE MEAN CHORD.

INDEPENDENT FROM THIS DISCHARGE METHOD, MY ASSISTANT MR. REGENSCHEIT DEVELOPED A SUCTION METHOD. THIS METHOD IS SHOWN IN FIGURE 2. THERE IS A SUCTION SLOT AT THE TRAILING EDGE OF THE WING WHICH IS SO SITUATED THAT THE END OF THE PRESSURE SIDE IS A LITTLE BIT LONGER THAN THE END OF THE SUCTION SIDE. IF THE AIR IS SUCKED THROUGH THE SLOT, A CONSIDERABLE LIFT INCREASE IS MEASURED. WITH THE OPPOSITE DEVICE OF THE END OF SUCTION SIDE LONGER THAN THE END OF THE PRESSURE SIDE A DECREASE OF LIFT IS MEASURED.

THE EFFECT CAN BE EXPLAINED IN THIS WAY. THE STREAMLINE WHICH SEPARATES THE SUCKED AIR QUANTITY FROM THAT WHICH IS NOT SUCKED (IN FIGURE 2 THE HEAVIER LINE) CREATES A NEW CONTOUR OF THE PROFILE, WHICH IS STRONGLY ROUNDED AT THE TRAILING EDGE.

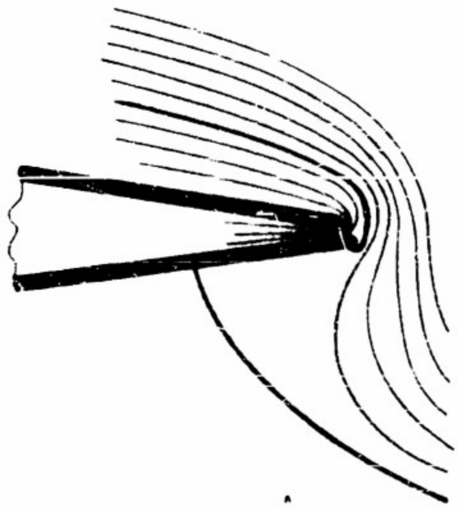

FIGURE 2.- STREAMLINES FROM SUCTION ON THE WING TRAILING EDGE.

BECAUSE THERE IS NO SURFACE FRICTION, AND THAT MEANS NO BOUNDARY LAYER ON THE IMAGINED PROFILE LIMIT, THERE IS NO FLOW DIVERSION. THE FLOW FOLLOWS THE VERY MUCH CURVED TRAILING EDGE AND THE POSTERIOR STAGNATION POINT MOVES TO THE PRESSURE SIDE. WITH THIS DEVICE ALSO VERY GOOD EFFECTS CAN BE OBTAINED. THE SUCTION QUANTITY, WHICH IS NECESSARY TO INCREASE THE LIFT COEFFICIENT c_A FOR 0.5, IS GIVEN BY THE QUANTITY COEFFICIENT $c_Q = 0.007$. IT IS ABOUT 40% SMALLER THAN FOR DISCHARGE.

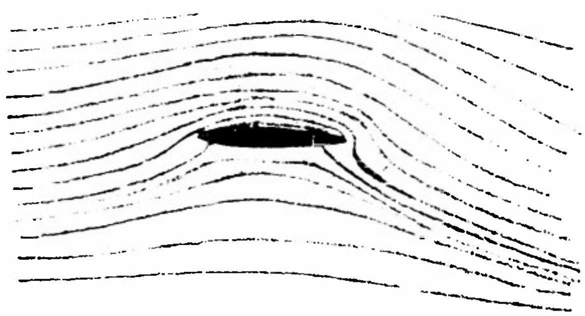

FIGURE 3.- STREAM AROUND A WING WITH TRAILING-EDGE SUCTION.

FIGURE 3 SHOWS A FLOW IN A HYDRODYNAMIC TANK. WE CAN OBSERVE FROM THE STRONG DEVIATION OF THE STREAMLINES, THE LARGE LIFT. AND BESIDES, THIS LIFT IS OBTAINED WITHOUT A LARGE ANGLE OF ATTACK.

HIGHER LIFT COEFFICIENTS WERE REACHED, WHEN DURING DISCHARGE INSTEAD OF A SIMPLE ROUNDING OF THE TRAILING EDGE A VARIABLE FLAP WAS USED AND DURING SUCTION A SPLIT FLAP WAS USED.

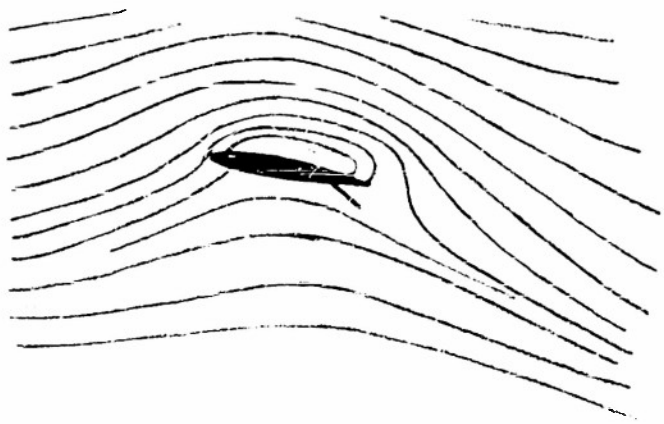

Figure 4.- Stream around a wing with a split flap and trailing-edge suction at high lift.

Figure 4 shows the mentioned arrangement and the corresponding flow. We see that the flow is completely separated at the leading edge, but is attached again at the trailing edge. If with this device with almost constant suction the velocity of the wind tunnel is decreased the lift is not decreased proportionally, but lift coefficients were obtained which were completely unknown for wings. With both the suction and the discharge method values were obtained. To give an idea of the meaning of these values, I only want to mention that the maximum lift coefficients of the usual wing are about 1.5. With landing flaps and similar devices lift coefficients of 2.5 can be reached. With the present boundary-layer suction in connection with flaps we can obtain lift coefficients around 4. Only the rotary cylinder gives a similar lift coefficient.

The high coefficients of the wing are very surprising, since the theoretical maximum value for a flat plate, which is obtained when the front and the rear stagnation points converge on the pressure side, is 2π or about 6, so naturally we must ask how such a high lift coefficient is possible.

In the case of discharge, the high lift partially can be explained that the reaction of the bottom deflected discharge jet gives a part of the lift; but it does not seem to be the main part. In the case of the suction such an explanation is impossible. There are ideas for a theoretical explanation, but I hesitate to discuss it because too little is known. I want to mention only one thing: apparently the high lift coefficients appear for suction only if at almost constant suction we decrease the velocity. While starting at higher velocities the values are not so high.

The suction and discharge quantities at which the unusually high lift coefficients of $c_A = 10$ were measured are very large, so there is no practical use at this time for the unusual values. In order to obtain lift coefficients $c_A = 10$ a required discharge quantity coefficient of $c_Q = .075$, but with suction $c_Q = .23$. At medium lift coefficients ($c_A = 3$ to 6) the consumption in suction is still large but tolerable. But as these high lift coefficients are usually needed only for a very short time as for landing or in air combat, we can imagine that the suction or discharge outputs could be created by rockets with similar results. Regardless of these practical possibilities, the discovery that it is possible to realize flows with such unusual lift coefficients seemed of enough importance to me to report about it here.

The second configuration of the swept-wing, blowing-duct mockup was fabricated and tested. The results were very favorable. As a comparison with the first configuration:

1st Configuration	2nd Configuration
$Q = 9.85\ ft^3/sec$	$Q = 10.0\ ft^3/sec$
$V_{avg_{exit}} = 398\ ft/sec$	$V_{avg_{exit}} = 409.5\ ft/sec$
Duct losses $= 122.5\ lb/ft^2$	Duct losses $= 80.4\ lb/ft^2$
$= 4.875\ q$	$= 3.2\ q$
Avail. Energy $= 178.0\ lb/ft^2$	Avail. Energy $= 189.2\ lb/ft$
$= 7.1\ q$	$= 7.55\ q$

In these relations the tunnel dynamic pressure, q, was assumed to be 6 inches of alcohol or 25.3 pounds per square foot.

The velocity distribution improved considerably along the entire span. From the root (Sta. 42.75) to approximately Sta. 65.00, the velocity increased slightly and was generally more stable. From Sta. 65.00 to Sta. 75.00 (Sta. 72.35 the tip), there was 25 percent less decrease in velocity for the second configuration than for the first.

The above results required a design change in the swept wing BL-C model (ONR-RM-5). The blowing-duct mockup is now being changed to a suction-duct mockup.

Jet pump.- The steam jet pump experimental program was temporarily discontinued until a steam superheater is received and installed. A preliminary report was prepared which outlined the experimental results obtained from the present pump